BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 12020

SUBJECT: Can High Latitude Sites be Their Own Recycle Sites? - Case 340

DATE: December 3, 1969

FROM: D. B. James

ABSTRACT

The approach to high latitude sites will have an azimuth to the sun, first due to the high inclination of the trajectory and second due to the azimuth of the sun line to a line of latitude, giving rise to improved landing visibility than that of equatorial sites. Further, the range of sun elevations over which good visibility extends will allow more launch opportunities and the possibility of using a site as its own recycle site.

It is concluded that from the point of view of visibility alone

(a) sites with latitudes greater than 20° can be targeted for the first day (lunar dawn) and any subsequent day until glare becomes a problem and

(b) sites with latitudes less than 20° can be targeted for on the first day, depending on the latitude on the second day, and then on the fifth day and subsequent until glare becomes a problem.

Since these conclusions offer the possibility of opening up the lighting band and the launch windows, the impact of other factors, such as thermal, should be examined.

(NASA-CR-108146) CAN HIGH LATITUDE SITES BE THEIR OWN RECYCLE SITES /QUES/ (Bellcomm, Inc.) 13 p

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MEMORANDUM FOR FILE

Introduction

Currently the Apollo Program recognizes the following lighting constraint for equatorial landings viz. 5° to 14° and 18° to 20°. This constraint arose from the following considerations:

(a) 7° was considered the lowest sun angle to avoid excessive shadowing (later Apollo 8 and 10 photographs allowed this limit to be moved to 5°).

(b) The moon rotates 13° between launch opportunities (∿25 hours) and to ensure that a site was available for at least one day a month the window had to be 13° wide, i.e., 7°-20°.

(c) Since the flight path angle of the LM was approximately 16°, a sun elevation of 16° could lead to zero phase conditions and washout hence a small band around 16°, i.e., 14° to 18°, was eliminated.

These factors led to the assumption of the 5° to 14° and 18° to 20° constraint.

It is well known to students of the lunar photometric function that scene contrast remains high as one approaches zero phase and washout from the low side since shadows can be seen until the last moment. Above the zero phase point (sun above the observer) no shadows can be seen. Further, in this region the photometric contrast is very very low and the rate of increase of contrast with phase angle is about 1/50 of that in the case of sun angles less than the viewing angle. Thus a 5° to 13° constraint leads to excellent photometric contrast and shadows while an 18° to 20° constraint leads to extremely poor contrast - nearly washed out. Apollo 8 and 10 crews have made statements saying that washout "was not all that bad" and they could see details. This is true, since albedo changes are not effected by zero phase and thus fresh craters with high albedo rays will provide scene contrast in this region (18° to 20°), however, older subdued craters with no albedo change will be essentially invisible even though they contain slopes which will be hazardous for landing. Finally, it is also well known that poor contrast conditions near zero phase can be greatly improved if the scene can be viewed with an azimuth angle to the sun line. High latitude sites automatically produce such an azimuth, first, from the angle of the sun to a line of latitude and, secondly, from the angle of the flight path direction to a line of latitude. These factors, triggered by reading R. A. Bass' memorandum[1] on the visibility for high latitude sites led to the idea that high latitude sites might have sufficient scene contrast to act as their own recycle sites.

This memorandum calculates the contrast for these conditions and determines the conditions under which a site could be used as its own recycle site from the point of view of visibility. It does not consider other factors such as thermal effects on the LM.

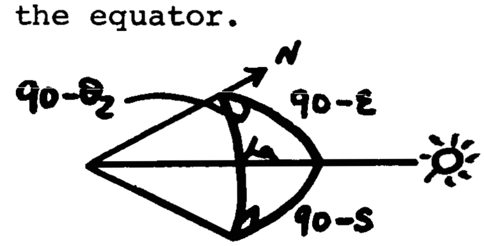
Calculation of Scene Contrast

Scene contrast is a function of

(a) the slope of local obstacles relative to the background. Here we assume a 10° cone or crater and calculate the maximum contrast.

(b) the sun elevation "ε" at the landing site which in turn is a function of the sun elevation "S" at the equator at the same longitude and the latitude "La" of the site. Here we assume that the subsolar point always lies on the equator.

From spherical geometry



$$\sin \varepsilon = \cos La \sin S$$

or $$\varepsilon = \sin^{-1}(\cos La \sin S)$$

(c) the azimuth of the viewing direction (which is assumed coincident with the flight path angle) to the azimuth of sun "Θ". Θ can be broken up into two parts, the azimuth of the flight path to a line of latitude, Θ_1, and the azimuth of the sun to a line of latitude, Θ_2.

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[1] Improved Lunar Landing Visibility Resulting from Greater Expected Relative Sun Azimuth for High Latitude Sites - Case 310, Bellcomm Memorandum for File, R. A. Bass, October 15, 1969.

Again from spherical geometry

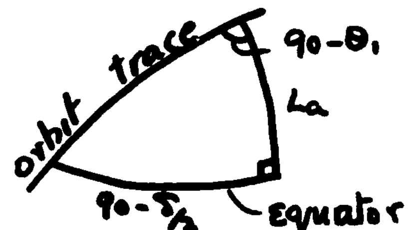
$$\tan \theta_2 = \sin La \tan S$$

or $$\theta_2 = \tan^{-1}(\sin La \tan S)$$

The calculation of θ_1 requires some assumptions about the trajectory. Here we assume that the landing point of the LM lies under the track of the CSM and further that the track of the CSM at lift-off lies over the LM, i.e., no plane change in ascent or descent.* Further for simplicity we assume that the CSM made no plane change between descent and ascent. A staytime of 54 hours, i.e., a sun angle change $\delta = 30°$ at the equator, is assumed.

Then

$$\tan \theta_1 = \sin La \tan \delta/2$$

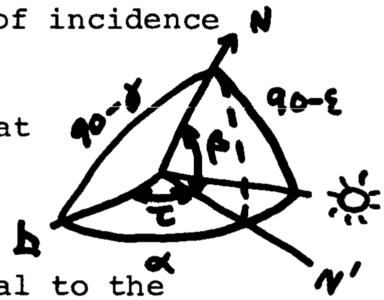


or $$\theta_1 = \tan^{-1}(\sin La \tan \delta/2)$$

and $$\theta = \tan^{-1}(\sin La \tan \delta/2) + \tan^{-1}(\sin La \tan S)$$

The Photometric Function from which the contrast is derived is usually stated in terms of the following variables:

(a) Phase angle α, the angle between the line of incidence and the line of emission. See Figure 1.



From spherical geometry it can be shown that

$$\cos \alpha = \sin \varepsilon \sin \gamma + \cos \varepsilon \cos \gamma \cos \theta$$

where γ is the viewing angle, here assumed to be equal to the flightpath angle and having a value of 16°.

(b) Luminance Longitude τ, the angle between the viewing line and the projection N' of the surface normal N in the phase (α) plane, can be found from the spherical geometry

$$\tan \tau = \frac{\cos \alpha - \dfrac{\sin \varepsilon}{\sin \gamma}}{\sin \alpha}$$

The photometric function is independent of the Luminance Latitude β which can be expressed as:

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*Bass, ibid., discuss the conditions under which optimized trajectories deviate from this assumption.

$$\frac{1}{\cos\beta} = \frac{\cos\tau}{\sin\gamma}$$

The contrast, however, is a function of β and increases as β increases by the factor $\frac{1}{\cos\beta}$

In Figure 1 the photometric function derived from Fedorets' data[2] is shown.

Figure 2 is taken from Hamza[3] and superimposes an arbitrary definition of regions of good, fair and poor contrast on the photometric function where the division between good and fair is 10% for a 10° slope. Here the contrast calculation is based on the inplane case, i.e., viewing angle, surface normal and sun angle all in the same plane, the phase plane.

Figure 3 plots the positions for a range of sun elevations at the equator of 0-90°, and a range of latitudes of 0-40°. Here we can see that when the sun elevation at the equator (proportional to time since sunrise 13° ≡ 1 day) becomes greater than 50° we find ourselves in a region of the photometric function where the contrast is fair.

Another way of displaying this data is by contrast plots. We can obtain the contrast of a slope § to the background from

$$C = \frac{\delta\Phi}{\delta\tau} \cdot \frac{1}{\Phi} \cdot \frac{\S}{\cos\beta}$$

Where § = 10°

The term $\frac{1}{\cos\beta}$ is added because a small perturbation of slope § produces a change in τ of (approximately) $\frac{\S}{\cos\beta}$.*

In Figure 4 we plot the contrast of the brightest ray of a 10° cone against its background, using the Fedorets' photometric function, for sun elevations at the equator of 0 to 90°, for viewing angle of 16°, for sites at latitudes of 0°, 10°, 20°, 30°, and 40°.

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[2] Natural Environment and Physical Standards for the Apollo Program and the Apollo Applications Program (Figure 5-4), Office of Manned Space Flight, M-DE 8020.008C, July 10, 1969.

[3] Lunar Lighting Conditions for the Apollo Lunar Landing Mission, Bellcomm TM-66-1012-6, V. Hamza, May 17, 1966.

*See appendix for derivation.

Superimposed are the arbitrary division of poor, fair, and good contrast boundaries mentioned previously.

Note (a) that all latitudes have excellent contrast for sun elevations less than the viewing angle,

(b) that all latitudes have fair to good contrast for sun elevations greater than 60°, and

(c) that latitudes above 20° have fair to good contrast for all sun elevations.

Conclusions

Therefore, it is concluded that consideration should be given to using a site as its own recycle site and specifically from the point of view of lighting

(a) sites with latitudes greater than 20° can be targeted for the first day (current constraint 5° to 13°) and any subsequent day until direct incidence of the sun on the windows (glare) becomes a problem.

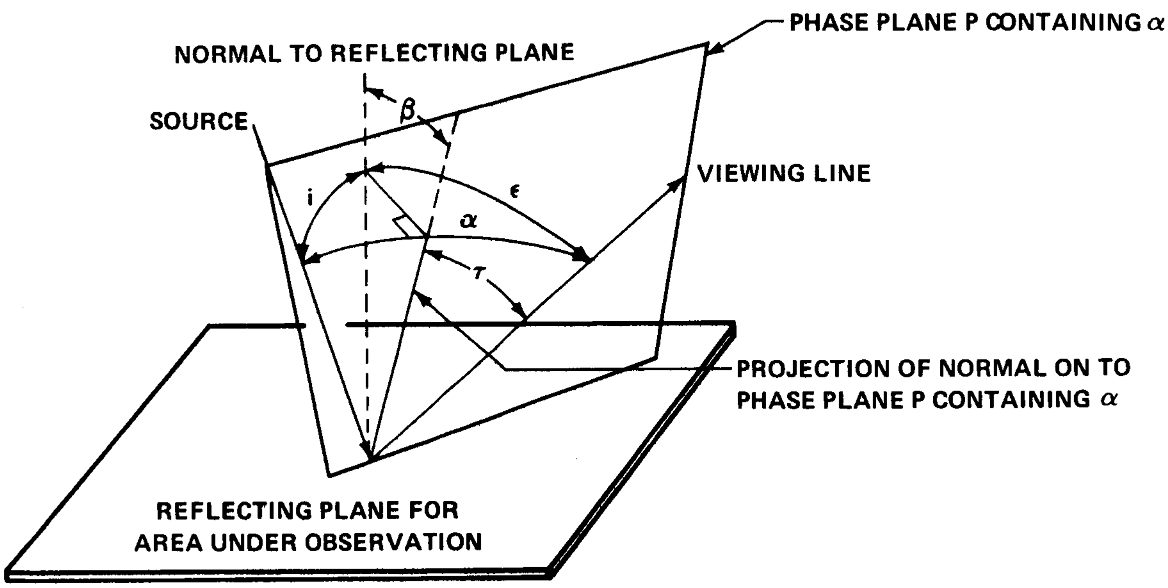
(b) sites with latitudes less than 20° can be targeted for on the first day, depending on the latitude on the second day and then on the fifth day and subsequent until glare becomes a problem.

Since these considerations offer the possibility of opening up the lighting band and the launch opportunities, the impact of other factors should be examined, e.g., thermal effects and mission ΔV requirements.

2015-DBJ-bab

D. B. James

Attachments
Figures 1-4
Appendix



i = ANGLE OF INCIDENCE
ϵ = ANGLE OF EMITTANCE
α = PHASE ANGLE
τ = PROJECTION OF ANGLE ϵ ONTO PHASE PLANE P OR LUMINANCE LONGITUDE
β = LUMINANCE LATITUDE

FIGURE 1 – DIAGRAM OF THE PHOTOMETRIC ANGLES i, ϵ, α, β, AND τ

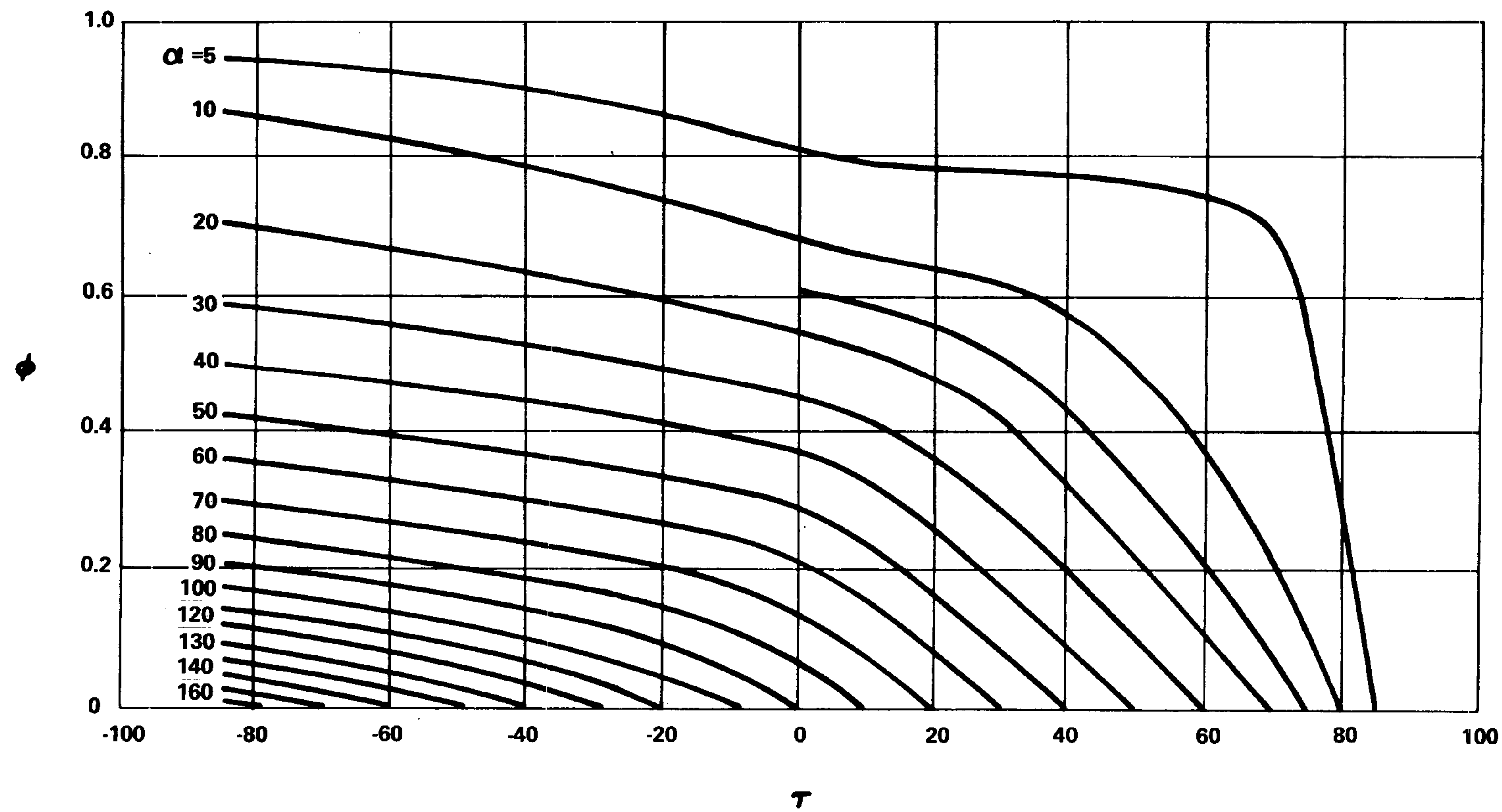


FIGURE 2 - PHOTOMETRIC FUNCTION ϕ VERSUS ANGLE τ

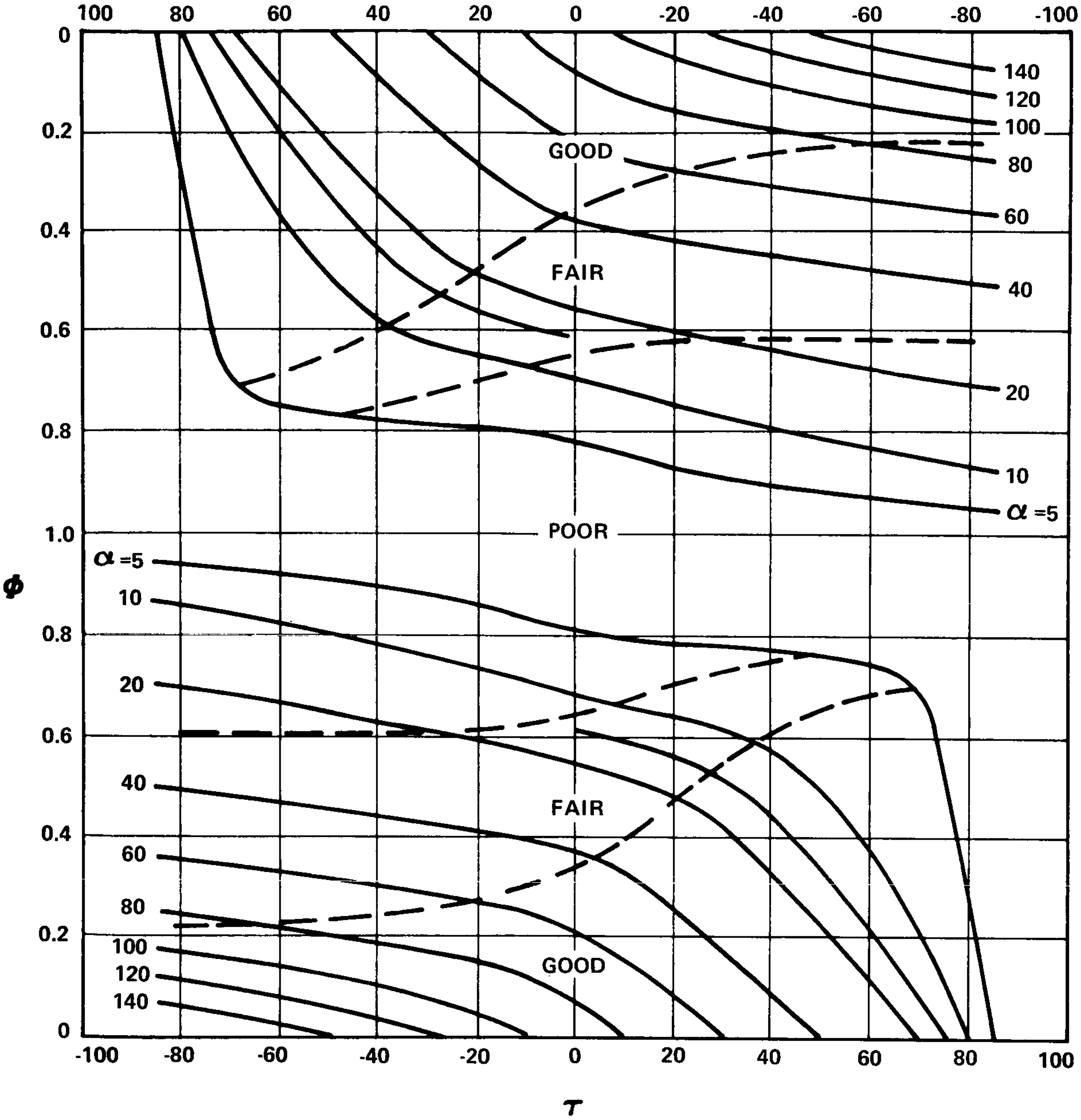


FIGURE 3 - LUNAR PHOTOMETRIC FUNCTION ϕ VERSUS ANGLE τ

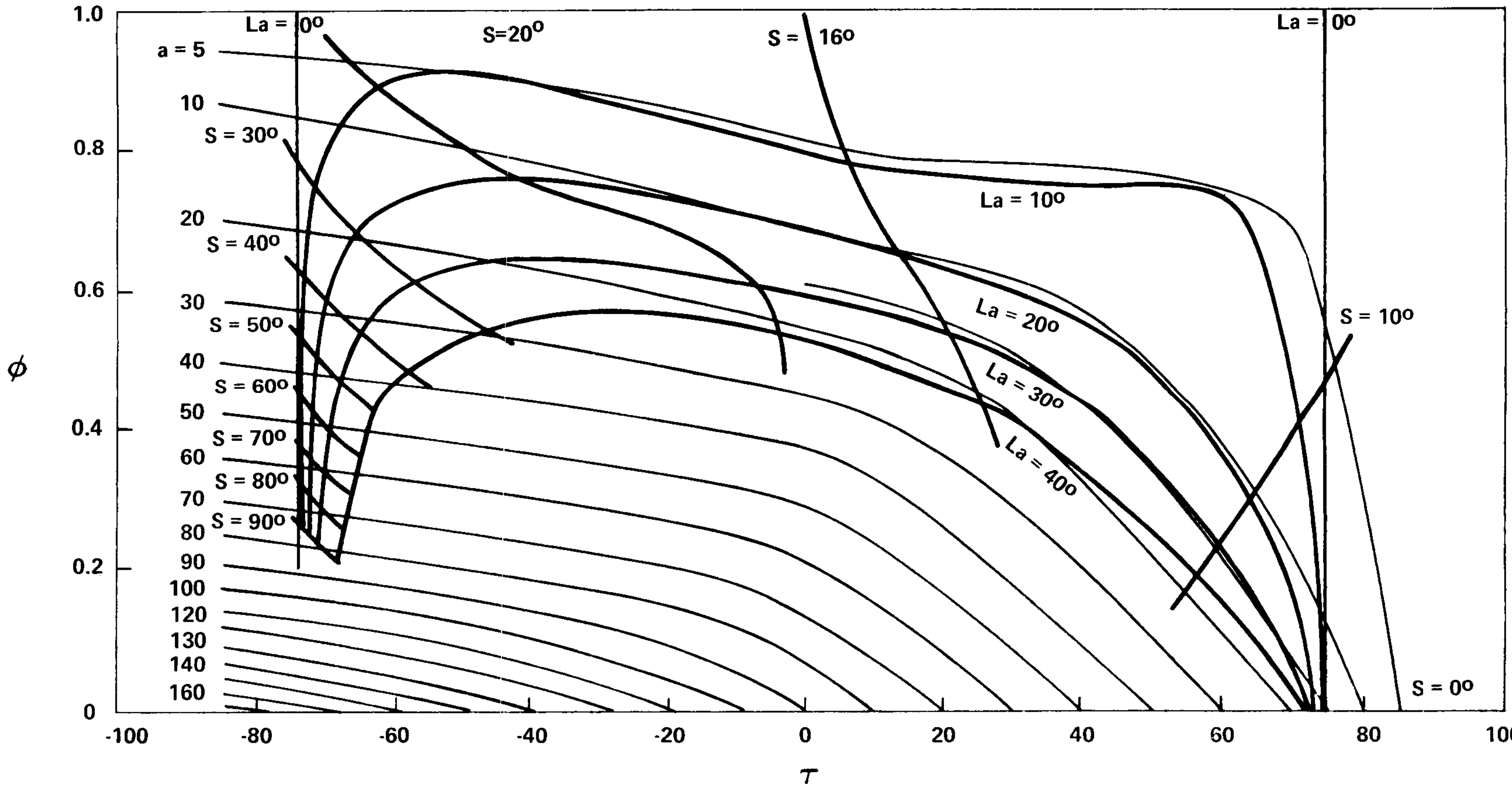


FIGURE 4 · PHOTOMETRIC FUNCTION VERSUS ANGLE SHOWING LIGHTING CONDITIONS AT LATITUDES La = 0°, 10°, 20°,30°,40° FOR SUN ELEVATIONS AT THE EQUATOR OF S= 0° TO 90°

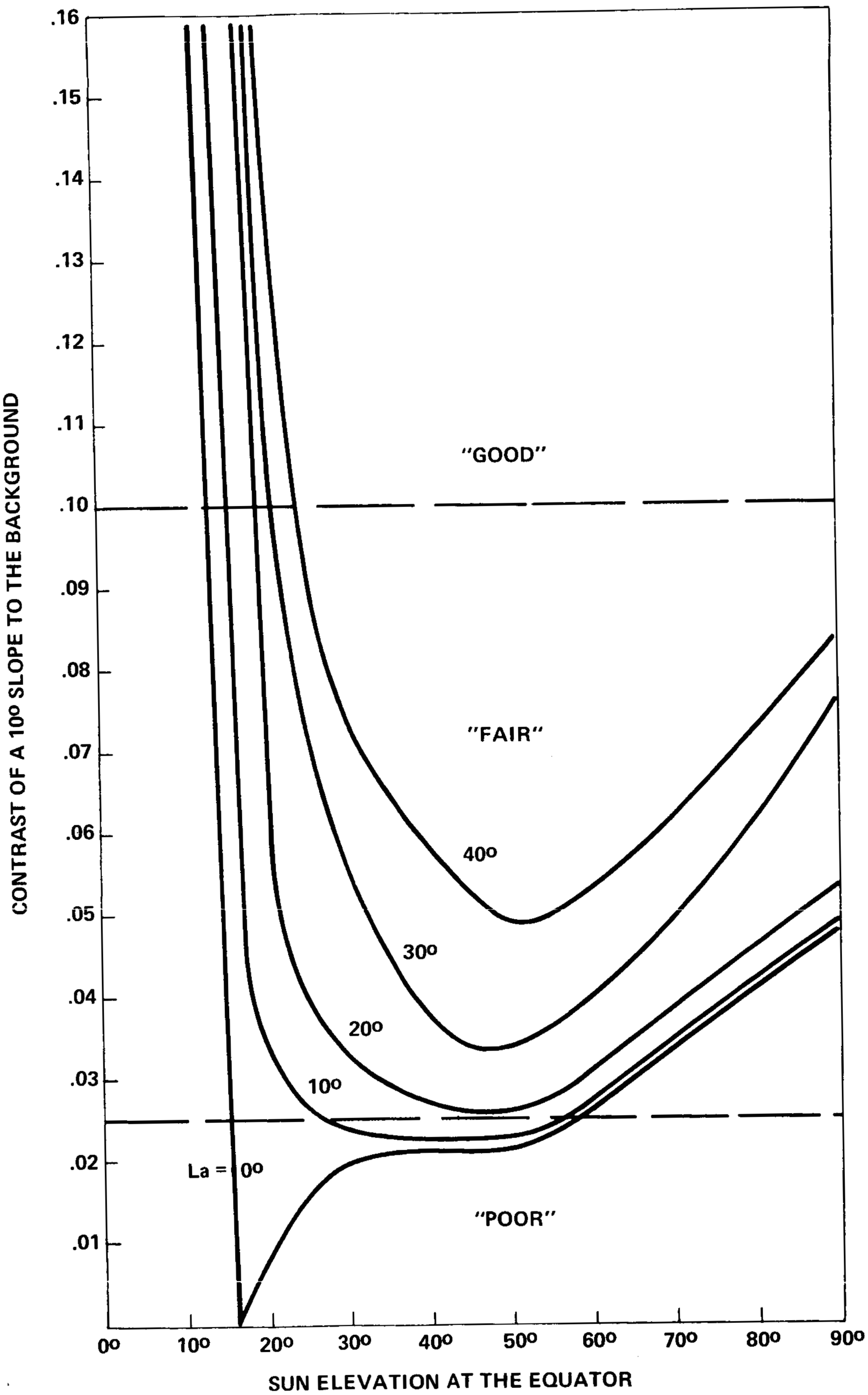
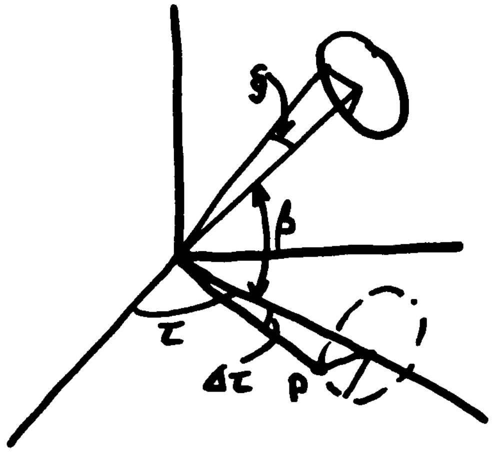


FIGURE 5 - SCENE CONTRAST (10° SLOPE) FOR VIEWING ANGLE OF 16° AT LATITUDES La = 0°,10°,20°,30°,40° AS A FUNCTION OF SUN ELEVATION AT THE EQUATOR

APPENDIX

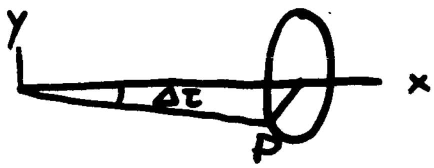
Derivation of contrast correction factor $1/\cos \beta$

Consider a cone with central angle § with the following geometry:



Projecting surface normal with the phase plane results in an ellipse with
semi-major axis tan §
and semi-minor axis tan § cos β

Rotating the coordinates through an angle τ results in the following geometry:



where the coordinates of P a point on the ellipse are

$$X_P = \cos \beta - \tan \S \cos \beta \sin \theta$$

$$Y_P = \tan \S \cos \theta$$

hence $$\tan \Delta\tau = \frac{\tan \S \cos \theta}{\cos \beta \,[1-\tan \S \sin \theta]}$$

differentiating and equating to zero to determine $\Delta\tau_{max}$ gives the condition

$$\tan \S = \sin \theta$$

and $$\tan \Delta\tau_{max} = \frac{\tan \S}{\cos \beta \sqrt{1-\tan^2 \S}}$$

$$\Delta\tau_{max} \simeq = \frac{\S}{\cos \beta} \text{ for small } \S.$$